Spring 2020

Macroalgae Aquaculture in Southwestern Florida as a Potential Tool for Nutrient Sequestration

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MACROALGAE AQUACULTURE IN SOUTHWESTERN FLORIDA AS A POTENTIAL TOOL FOR NUTRIENT SEQUESTRATION

by

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A thesis submitted in partial fulfillment of the requirements for graduation with Honors in the Environmental Sciences

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Thesis Mentor

Spring 2020

All requirements for graduation with Honors in the Environmental Sciences have been completed.

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Environmental Sciences Honors Advisor

MACROALGAE AQUACULTURE IN SOUTHWESTERN FLORIDA AS A POTENTIAL TOOL FOR NUTRIENT SEQUESTRATION

by

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An honors undergraduate senior thesis in Geoscience submitted to the
Department of Earth & Environmental Sciences at
The University of Iowa

May 2020

Thesis Supervisor: Associate Professor – Bradley D. Cramer

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Claire E. Carlson

Abstract

Excess nutrients from terrestrial sources have led to rapid growth of invasive, and often opportunistic, algal species, creating dead zones and causing degradation of the coastal ecosystem. Low levels of oxygen within these areas, an ultimate consequence of excess nutrient flux, contribute to harmful and deadly environments for marine life. Most macroalgae, however, are not harmful and are well known for the ecosystem services they provide, perhaps the most important of which is nutrient sequestration. The ability of macroalgae to sequester nutrients as part of their normal life cycle, combined with their potential market demand, illustrate that macroalgae can be used to restore eutrophic waterways while simultaneously creating economic opportunities through the practice of aquaculture.

To determine the viability of macroalgae aquaculture in Tarpon Bay, located in Sanibel, Florida, three testing sites along with two different treatment methods (enclosed vs. exposed) were established. All testing sites were equipped with two aquaculture lines with clusters of macroalgae attached by fishing line, as well as macroalgae samples enclosed in mesh bags. The goal of this project was to see which of three species of macroalgae would grow best, which treatment method was best for aquaculture success, which locality within Tarpon Bay would lead to the greatest amount of algal growth, and which environmental parameters were most important for overall growth of each species.

Introduction

In many coastal areas, dead zones have formed due to the increased levels of nutrient inputs, such as nitrogen (N) and phosphorous (P), most often originating from terrestrial and anthropogenic sources upstream (Savage and Elmgren, 2004). Inputs of nutrients at such a large scale have led to rapid algal growth on the water's surface (Teichberg et al., 2010) after which the algae subsequently dies and sinks to the ocean floor. The decomposition of this organic material at the sea floor removes large amounts of oxygen from the water column and this cycle of rapid growth and subsequent death has led to a depletion of dissolved oxygen throughout coastal areas, creating large anoxic zones unfit for aquatic life (Myers, 2015).

Macroalgae (e.g., seaweed) is well-known for the role it plays in sequestering excess nutrients such as nitrogen and phosphorous. Algal blooms, which can take the form of micro- or macroalgae, lead to eutrophication of coastal areas and can be detrimental to coastal environments (NOAA Ocean Service Education, 2020). Most macroalgae, however, are not harmful and the plant itself is a eukaryotic organism that attaches to non-mobile features, such as rocks or coral, via a holdfast, or floats throughout the water column. Due to macroalgae's ability to withdraw large amounts of nitrogen and phosphorous from waterways, it has the potential to be used for restoration efforts in eutrophic zones and combat the excess growth of opportunistic and harmful algal blooms such as red tide (Teichberg et al., 2010; Myers, 2015; Hall, 2018). Another benefit derived from macroalgae is its ability to drawdown carbon from the atmosphere. While the title "Blue Carbon" is controversial in relation to macroalgae's sequestration abilities, it describes carbon that is naturally sequestered by coastal and marine ecosystems (Mcleod et al., 2011). Coastal ecosystems' dense vegetation, leafy canopies, and complex root structures allow them to be extremely efficient in sequestering carbon (Mcleod et al., 2011), comparable to, if not better than, those of terrestrial ecosystems. This capability also allows the macroalgae plant to play a small role in mitigating climate change by helping to sequester some of the 2.48 million tons of CO_2 in the atmosphere (Duarte, 2017). Additionally, maritime plants such as kelp forests, seagrass meadows, salt marshes, and mangrove forests, assist in capturing carbon before it is released into the atmosphere (NMSF, 2018).

In Southern Florida, Lake Okeechobee is well-known for its polluted waters. It is these same waters that pump excess nutrients through the Caloosahatchee River and into Tarpon Bay (CSF, 2019). The nutrients found in this lake are drivers of the harmful algal blooms that take over aquatic systems and kill aquatic life (CSF, 2019). Water contamination can be linked to multiple point sources in the region, including both anthropogenic factors and industrial wastewater (Haji Gholizadeh et al., 2016). Fertilizer from agricultural practices, a primary industry throughout much of Southern Florida, has experienced drastic increases in both production and usage. Since the 1950s, global production of nitrogen-based fertilizers has risen from less than 10 million metric tons/year to 80 million metric tons/year in 1990. This amount is expected to more than double to 135 million metric tons/year by 2030 (Vitousek et al., 1997).

The EPA, according to the Pollution Prevention Act, emphasizes that coastal states *"…must establish a source reduction program which collects and disseminates information, provides financial assistance to States, and implements the other activities…*" (EPA, 2019). Though the Act primarily focuses on point source pollution reduction, efforts can be stymied due to regulations in place, in addition to lack of viable and available technological resources (EPA, 2019). However, macroalgae aquaculture can be one of these programs. In comparison to mainstream agriculture practices, macroalgae aquaculture, or "farming", does not require the use of arable land. Instead, it utilizes coastal regions in an already degraded environment.

Additionally, macroalgae farms (algal scrubbers) are non-traditional Best Management Practices (BPMs) that yield approximate absorption of 3.5% nitrogen, 0.1% phosphorus, and 30% carbon per plant (Myers, 2015); presently, similar practices have been deployed in other parts of Florida as well (Chesapeake, 2020).

Globally, the popularity of macroalgae as a commercial product has grown significantly in the past decade. Its uses range from food sources for humans to feedstock and biomass fuel (Mariner, 2016). Increasing demand for these plants as food products has enabled countries like China and Indonesia to become leaders in production. Because these crops do not require a freshwater source, "feeding" with nitrogen, and are better at fixing carbon dioxide than traditional terrestrial plants, the practice of macroalgae aquaculture is a very appealing way to develop their potential for use within the renewable energy sector, along with other sectors of the economy (Mariner, 2016). However, even though production of macroalgae would be cost competitive on a large scale in the U.S., the intensive labor practices and under-developed technology have prevented this aquaculture practice from truly advancing, causing the U.S. to drastically lag behind Asian and South American countries.

The purpose of this project is to test the differences in growing ability of macroalgae species *Gracilaria bursa-pastoris*, *Gracilaria tikvahiae,* and *Acanthophora spicifera* in the marine environment of Tarpon Bay in Southwestern Florida. All three species were utilized in all three localities chosen, and each was given two treatments (enclosed or exposed) in each setting. Factors influencing the growing ability of the macroalgae will be discussed further in the Project Methods section. Through the controlled aquaculture practices, the project will help provide insight on the viability of future larger-scale aquaculture in Florida as potential economic benefit and conservation effort through sequestration of nutrients and reduction of atmospheric carbon.

Project Location

This project was carried out through the Sanibel-Captiva Conservation Foundation (SCCF) within Tarpon Bay, which is located on the north-eastern part of Sanibel Island and is a component of the J.N. Ding Darling National Wildlife Refuge (Fig. 1). The first site (Back of Bay) was located in a protected area at the back of Tarpon Bay next to a mangrove forest where water movement is limited. The second site (Shallow Cut) was located in a central area of the bay where tidal action was consistent. The third location was at the mouth of Tarpon Bay (Green Point) in a sandy area near the shoreline where disturbance from boat wakes may cause fragmentation to macroalgae clusters. These three locations provided a variety of environmental settings including variations in depth, wave action, and tidal flow.

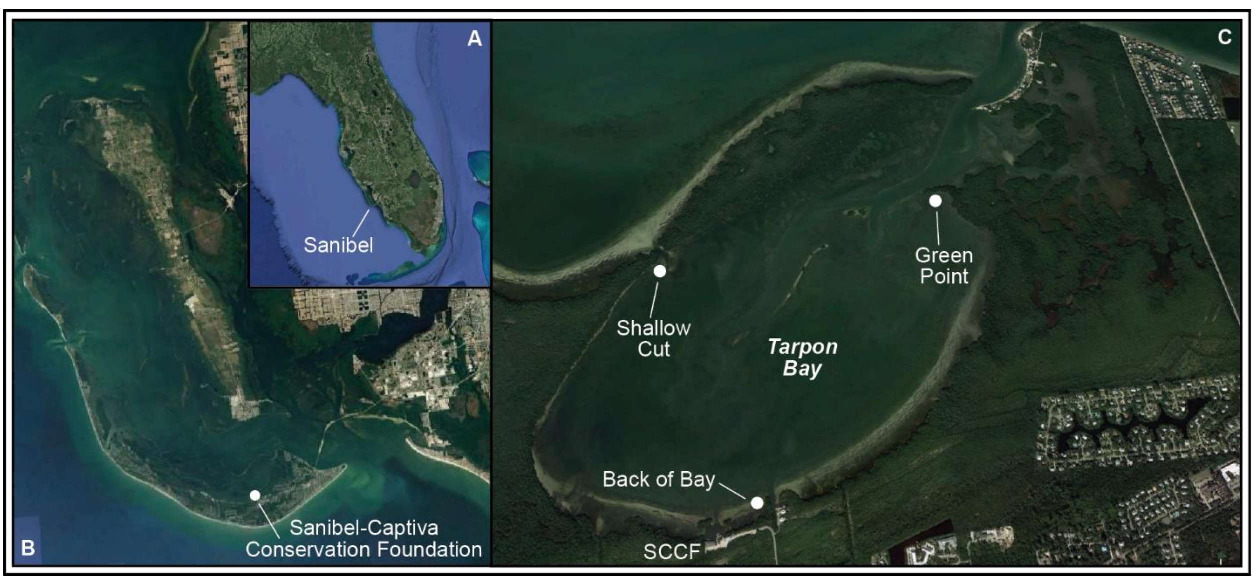

Figure 1 *- Locality map of A) Sanibel Island in SW Florida, B) Inset map of Sanibel Island showing location of the SCCF, C) Close up map of Tarpon Bay showing the three sample localities.*

Project Methods

The project spanned a total of four weeks during the months of July and August of 2018. Each of the three testing sites were equipped with two macroalgae aquaculture lines, one featuring exposed macroalgae attached by fishing line and the other held macroalgae samples that were contained in mesh bags. The objective of varying treatments was to see which method led to the greatest amount of algal growth. Initial volumes of the macroalgae were taken at the start of the project and continuously taken every week to document growth. To do this, a 400 mL vial was used, and an initial 300 mL of water was placed in the vial, after which a cluster of macroalgae was added to the vial and a measurement of water displacement was taken from the initial 300 mL volume to calculate the total volume of the macroalgae.

In addition to physical growth measurements, a series of environmental parameters were recorded at each site as well. A YSI sonde was used to measure pH, salinity, temperature, dissolved oxygen (DO), turbidity (NTU), chlorophyll (Chl), dissolved organic matter (cDOM), and manual measurements of depth, and daily weather were recorded (Table 1). Additionally, daily site checks were conducted to look for evidence of fouling from as grazers, and to ensure the integrity of the macroalgae clusters.

Furthermore, HOBO sensors were deployed at the beginning to the experiment and removed at the end. They were placed at all three sites and were programmed to record light and temperature data every 15 minutes. Relative water flow was measured using a clod card dissolution technique. A pre-weighed clod card, created from plaster of Paris, was held at a fixed position and attached to the aquaculture line for three days. The remaining clod card was then brought back to the lab and re-weighed, where the dissolution rate was calculated from the difference between preand post-weight clod card. These measurements provide a relative comparison of the total flow at each locality.

As a test of physical strength of each species, stipe strength tests were conducted on the stems of all three macroalgae species. This test provided a basis of comparison between all three species in order to determine which would be able to remain intact when subjected to environmental conditions and human pressures (i.e., boat traffic) in Tarpon Bay, and may help to explain some of the results recovered from this project.

Results

Physical parameters of depth, flow, and salinity were measured at each location and their relationships are shown in Figure 2. Depth and flow are much less correlated than salinity and flow, illustrating that the salinity of each site is largely controlled by the recharge flow present at each site. When attached to the exposed macroalgae line, both *Gracilaria bursa-pastoris* and *Acanthophora spicifera* species showed significant increases in growth when compared to the enclosed lines; *Gracilaria tikvahiae* did not follow this trend (Fig. 3). The most significant overall growth was with *A. spicifera*, followed closely by *G. bursa-pastoris*, both with the exposed treatment method. Each of these two species showed considerably less growth with the enclosed

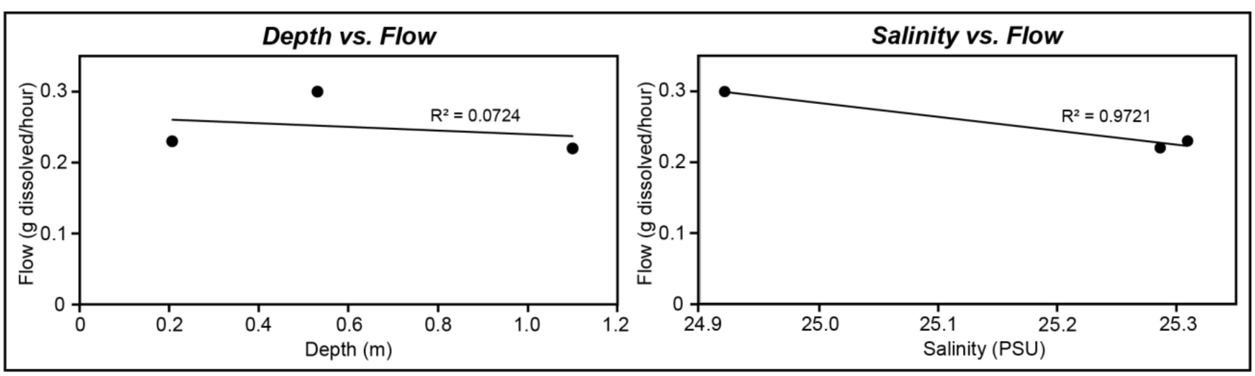

Figure 2 *- Depth and salinity vs. flow at each of the three test sites*

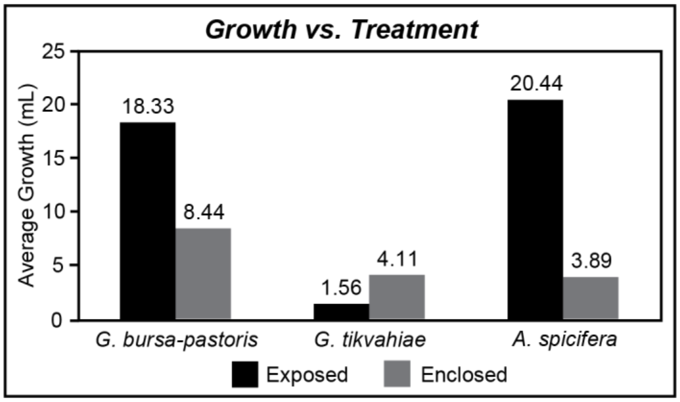

Figure 3 *- Average growth of all locations by treatment*

treatment. The species *G. tikvahiae* had by far the lowest total growth in the exposed treatment and only slightly more than *A. spicifera* in the enclosed treatment. The total growth data suggest that either *G. bursa-pastoris* or *A. spicifera* would be better candidates for potential aquaculture in Tarpon Bay than *G. tikvahiae*.

There was a direct and negative correlation between the growth of the species *A. spicifera* and *G. tikvahiae* and increasing water depth. These species performed best at the back of bay site where water depth is 0.206 m, and the worst at green point where water depth reaches 1.1 m. This indicates that the growth of species *A. spicifera* and *G. tikvahiae* were both controlled by water depth, whereas *G. bursa-pastoris* was not as heavily affected by increasing water depth.

There was a direct and negative relationship between the growth of *G. bursa-pastoris* and flow rate. This indicates that areas with high flow, like those found at the green point and shallow cut sites, do not provide optimal conditions for growth of this species. Neither *A. spicifera* nor *G. tikvahiae* appear to have been affected by flow rates. Other factors influencing the growing ability of the three macroalgae species included pH, temperature, and salinity. The pH was a major control on the growth of the species *G. tikvahiae* and the growth of the species increases with increasing pH. For *G. bursa-pastoris*, warmer temperatures and increasing salinity lead to increased growth for this macroalgae species.

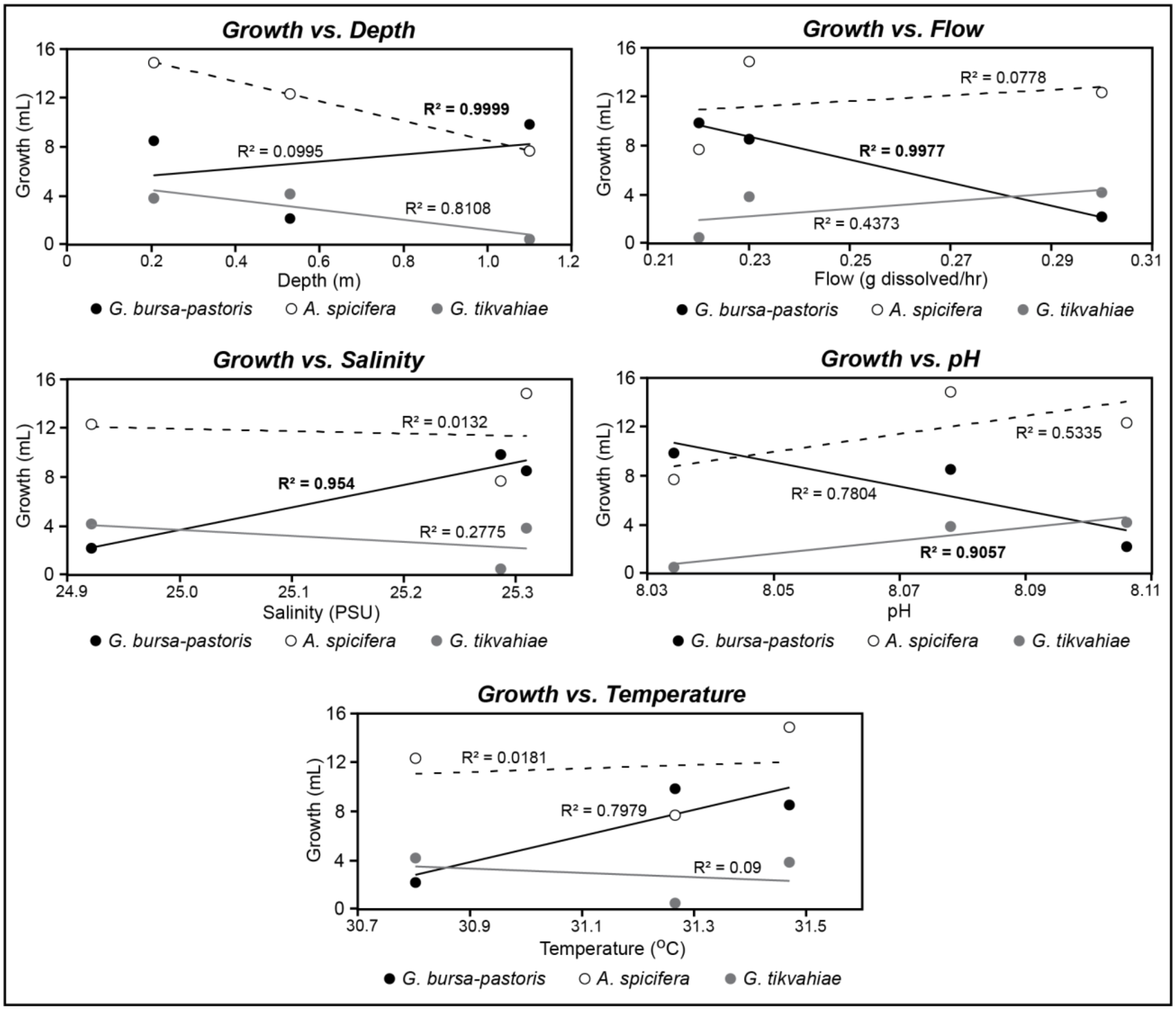

Figure 4 *- Growth of each species compared to depth, flow, salinity, pH, and temperature*

Discussion

The results presented in Figure 4 demonstrate very significant correlations between specific environmental parameters and controls on growth for each species. For *G. bursa-pastoris*, flow rate was the dominant environmental factor with an R^2 value of 0.9977. This was followed by, salinity with an R^2 value of 0.954, temperature with an R^2 value of 0.7979, and pH with an R^2 value of 0.7804. These findings indicated that areas featuring lower flow rates, increased salinity, and warmer temperatures would be most suitable for this species within Tarpon Bay. The environmental factor most influential for the species *A. spicifera* was depth with an R^2 value of 0.9977. Therefore, shallower areas within Tarpon Bay would be more suitable for this species. Lastly, pH, with an R^2 value of 0.9057, was the dominant environmental factor influencing the growth of *G. tikvahiae* and indicated that this species grew best in areas of lower pH.

As demonstrated by the Growth vs. Treatment graph (Fig. 3), increased exposure to the environment allowed macroalgae clusters to access greater amounts of sunlight and nutrients than they would have if enclosed in mesh bags. Enclosure prevented these fundamental and necessary resources from accessing the algal clusters with ease. Additionally, they acted similar to petri dishes used in a lab by creating an environment that encouraged growth and collection of moss-like vegetation on their surface, which further prevented adequate sunlight and nutrients from accessing macroalgae enclosed within. If the experiment were to be repeated in a similar manner, daily or weekly cleanings would need to be done on mesh bags to ensure the viability of the macroalgae contained within.

Due to the negative trends established by *G. tikvahiae* and *A. spicifera* in the Depth vs. Growth graph (Fig. 4), it is apparent that increasing depth negatively impacts their growth. Whereas both of these species can grow in depths of up to 10 m in certain geographic areas, they are more commonly found in shallow marine waters (Hill, 2001; Global, 2020). *Gracilaria bursa-pastoris* was not as heavily impacted by water depth as the other two test species even though it is generally found throughout shallow, warm waters that are sheltered (Marinho-Soriano, 2012; Guiry and Guiry, 2020).

The clod card dissolution rates and subsequent algal growth documented on the Flow vs. Growth graph (Fig. 4) demonstrate that *G. bursa-pastoris* is unable to withstand increased flow rates. *G. bursa-pastoris* is classified as a sublittoral algal species that is commonly found in

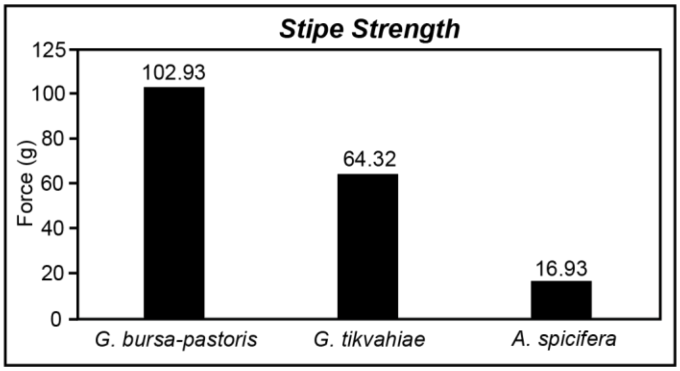

Figure 5 - *Stipe strength averages for each species*

generally sheltered areas (Guiry and Guiry, 2020), and this growth limitation explains why this species was unable to withstand sites like shallow cut and green point that experienced higher flow rates. These two localities host greater flow rates due to their placement within Tarpon Bay (Fig. 1), and both are heavily impacted by the wakes from boat traffic in the area. Additionally, the species *G. tikvahiae* and *A. spicifera* can be found in both quiet and high energy environments (Hill, 2001; Global, 2020), and the data support this by demonstrating that the growth of *G. tikvahiae* and *A. spicifera* were not hindered by increased flow rates of shallow cut and green point. This observation likely cannot be attributed to species' stipe strength (Fig. 5). Stipes are essentially algae stems and the ability of the stipe to remain intact when exposed to various environmental conditions allows them to be better or less suited for certain maritime locations that experience higher energy. As shown in Figure 5, *G. bursa-pastoris* has the highest stipe strength (Table 2) and therefore this does not seem like a likely reason for flow to have been negatively correlated with growth in this species. It is more likely that the apparent relationship between flow and growth for *G. bursa-pastoris* is actually responding to the relationship between salinity and growth (Fig. 4) as this species is also strongly correlated with salinity and as seen in Figure 2, salinity is largely responding to flow.

As demonstrated by the pH vs. growth by species graph, *G. tikvahiae* is highly influenced by pH, which is 8.2 for average seawater, but can range from 7.5-8.5 depending upon the local water conditions (University of Florida IFAS, 2020). As can be seen from the graph and the statistically significant R^2 value of 0.9057, growth of *G. tikvahiae* was strongly correlated to where localized environmental conditions lead to an increase in the pH of the water, even though the total growth of this species remained relatively low overall. During the summer of 2018, at the time this project was conducted, Southwestern Florida was experiencing unprecedented levels of eutrophication that led to the proliferation of a harmful algal bloom commonly known as red tide (*Karenia brevis*). In addition to producing harmful toxins deadly to marine animals and irritating to humans, red tides also lead to formation of dead zones by depleting dissolved oxygen in the water (Hall, 2018; NOAA, 2020). Depletion of dissolved oxygen leads to eutrophication, which, in turn leads to an increase in the pH water (MacIntosh, 2017). *Gracilaria tikvahiae* abundance can often be attributed to highly eutrophic areas (Hill, 2001), making the local water conditions in Tarpon Bay during this time frame more favorable for this species. It is interesting to note however, that even with this advantage, the overall growth of *G. tikvahiae* was generally one of the lowest at each location across all environmental conditions.

Results from the growth vs. temperature graph demonstrate that only *G. bursa-pastoris* was positively impacted by slightly warmer waters. *Acanthophora spicifera* typically thrives in relatively deeper depths that offer cooler water temperatures (Global, 2020), and the optimal growth temperatures for *G. tikvahiae* are 24-30 °C (Hill, 2001). Therefore sites within Tarpon Bay were slightly too warm for these species optimal growth conditions. However, *Graiclaria bursa-pastoris* is well suited for the warm waters present in the shallow depths of the bay (Guiry and Guiry, 2020).

The salinity vs. growth by species data indicate that *G. bursa-pastoris* is strongly influenced by salinity levels within water. Salinity and water temperature share a strong, positive correlation (Marinho-Soriano, 2012), and when combined, can influence *G. bursa-pastoris* growth. Due to the warm water conditions within Tarpon Bay, and its relatively low salinity levels

(~25 psu) when compared to the oceanic average of 35 parts per thousand (NOAA, 2019), it apparent why *Gracilaria bursa-pastoris* was influenced by slight increases in salinity levels throughout the course of the experiment. The species *G. tikvahiae* is a euryhaline species that can withstand a wide salinity range (Hill, 2001) and surprisingly the lower salinity levels within Tarpon Bay did not appear to give this species a competitive advantage. Conversely, whereas *A. spicifera* has been shown to exhibit an increased tolerance of salinities, ranging from 25 to 40 psu, the higher the salinity, the greater the loss to the algae's overall biomass (Pereira et al., 2017) effectively making waters with higher salinity unsuitable for long-term growth of this species. The relatively low-salinity of the water in Tarpon Bay may therefore be primarily responsible for the generally strong growth of *A. spicifera* overall during this experiment. While there are many abiotic factors that are influential to algal growth, salinity is an environmental parameter that strongly influences the distribution, locally or regionally, of algae (Pereira et al., 2017).

Conclusion

Given that nutrient sequestration was the overarching goal of this project, it was necessary to determine which macroalgae species that was best suited in site-specific conditions and optimize nutrient sequestration. The species *G. bursa-pastoris* and *A. spicifera* both performed well in terms of their overall growth and, therefore, their potential to rapidly sequester nutrients. However, it is important to note that due to the ease at which *A. spicifera* fragments, in addition to its ability to float through the water as an individual stipe and latch on to other macroalgae clusters (such as samples in this experiment), growth data from this species may have been artificially elevated due to the addition of ambient *A. spicifera* attaching to sample specimens.

The strongest controls for each of the three macroalgae species are as follows: *G. bursa pastoris* thrives best in areas with low flow rate, higher salinity, warm temperatures, and lower pH. *Acanthophora spicifera* is predominantly controlled by depth and grew better in testing sites that were shallow. Finally, *G. tikvahiae* grew best in areas with a lower pH. Therefore, because *G. bursa-pastoris* had the second best growing rates when compared to *A. spicifera*, this species was deemed to perform the best throughout the entirety of this experiment, given the clarity of the growth data. As a result, if I were designing a macroalgae aquaculture farm in the Tarpon Bay area in Sanibel, Florida, I would ensure that it would be built in a shallow environment that would feature warm water temperatures and lower flow rates, higher salinity and a lower pH, and grow the species *G. bursa-pastoris*.

Coastal discharge sites are the optimal location for pollution accumulation given that river discharge carries an overwhelming amount of terrestrial pollutants to the coastal realm. Efforts, such as macroalgae aquaculture, are continuously being studied to determine aquaculture's viability in sequestering harmful nutrients in these areas. However, the use of freshwater macroalgae, or other native aquatic plants, has the potential to also clean water upstream before its final disposal in the ocean. The next step for this project is to begin testing the viability of freshwater macroalgae, or other freshwater plants, in order to determine the impacts such species have on degraded freshwater ponds or river system located upstream from coastal regions. Areas of specific interest are those in the Midwestern region of the United States due to their increased usage of nutrient-rich fertilizer and already degraded waterways.

Acknowledgments

I would like to thank Eric Milbrandt and the staff at the SCCF Marine Laboratory in Sanibel for providing me with the opportunity to come and participate in a research project, as well as enabling me to increase my knowledge about marine conservation. Additionally, I would like to acknowledge and thank the Iowa Center for Research by Undergraduates (ICRU) and The University of Iowa Environmental Sciences Development Fund for providing financial support for this unique opportunity.

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Table 1A - Growth Data

MACROALGAE GROWTH						
SITE	TREATMENT	SPECIES	Vol. (*i*) (ml)	Vol. (*f*) (ml)	ΔVOL. (ml)	ADDITIONAL INFO.
BACK OF BAY	EXPOSED	Gracilaria Bursa-Pastoris	16	23	7	Replaced week 2
BACK OF BAY	EXPOSED	Gracilaria Tikvahiae	10	26	16	Replaced week 1
BACK OF BAY	EXPOSED	Acanthophora-spicifera	5	50	45	Replaced week 1
BACK OF BAY	EXPOSED	Gracilaria Bursa-Pastoris	15	30	15	
BACK OF BAY	EXPOSED	Gracilaria Tikvahiae	5	1	-4	Replaced week 3
BACK OF BAY	EXPOSED	Acanthophora	5	50	45	Replaced week 1
BACK OF BAY	EXPOSED	Gracilaria Bursa-Pastoris	7	1	x	
BACK OF BAY	EXPOSED	Gracilaria Tikvahiae	11	12	1	Replaced week 2
BACK OF BAY	EXPOSED	Acanthophora	10	2	-8	Replaced week 2
BACK OF BAY	ENCLOSED	Gracilaria Bursa-Pastoris	10	12	2	
BACK OF BAY	ENCLOSED	Gracilaria Tikvahiae	2	2	0	
BACK OF BAY	ENCLOSED	Acanthophora	11	12	1	
BACK OF BAY	ENCLOSED	Gracilaria Bursa-Pastoris	25	38	13	
BACK OF BAY	ENCLOSED	Gracilaria Tikvahiae	3	10	7	
BACK OF BAY	ENCLOSED	Acanthophora	6	10	4	
BACK OF BAY	ENCLOSED	Gracilaria Bursa-Pastoris	1	15	14	
BACK OF BAY	ENCLOSED	Gracilaria Tikvahiae	2	5	3	
BACK OF BAY	ENCLOSED	Acanthophora	10	12	2	
GREEN POINT	EXPOSED	Gracilaria Bursa-Pastoris	10	12	2	Replaced week 1
GREEN POINT	EXPOSED	Gracilaria Tikvahiae	5	2	3	Replaced week 1
GREEN POINT	EXPOSED	Acanthophora	15	52	37	Replaced week 1
GREEN POINT	EXPOSED	Gracilaria Bursa-Pastoris	5	5	x	
GREEN POINT	EXPOSED	Gracilaria Tikvahiae	10	0	-10	
GREEN POINT	EXPOSED	Acanthophora	10	40	30	Replaced week 1
GREEN POINT	EXPOSED	Gracilaria Bursa-Pastoris	10	45	35	
GREEN POINT	EXPOSED	Gracilaria Tikvahiae	1	10	9	
GREEN POINT	EXPOSED	Acanthophora	10	10	0	
GREEN POINT	ENCLOSED	Gracilaria Bursa-Pastoris	7	10	3	
GREEN POINT	ENCLOSED	Gracilaria Tikvahiae	5	0	x	
GREEN POINT	ENCLOSED	Acanthophora	15	5	-10	
GREEN POINT	ENCLOSED	Gracilaria Bursa-Pastoris	2	11	9	
GREEN POINT	ENCLOSED	Gracilaria Tikvahiae	7	8	1	
GREEN POINT	ENCLOSED	Acanthophora	13	3	-10	
GREEN POINT	ENCLOSED	Gracilaria Bursa-Pastoris	10	20	10	
GREEN POINT	ENCLOSED	Gracilaria Tikvahiae	2	2	0	
GREEN POINT	ENCLOSED	Acanthophora	5	4	-1	
SHALLOW CUT	EXPOSED	Gracilaria Bursa-Pastoris	10	70	60	
SHALLOW CUT	EXPOSED	Gracilaria Tikvahiae	2	1	-1	Replaced week 2 (8 ml) and week 3
SHALLOW CUT	EXPOSED	Acanthophora	14	48	34	Replaced week 2
SHALLOW CUT	EXPOSED	Gracilaria Bursa-Pastoris	10	52	42	
SHALLOW CUT	EXPOSED	Gracilaria Tikvahiae	2	2	0	Replaced week 1 (5 ml) and week 3
SHALLOW CUT	EXPOSED	Acanthophora	14	15	1	
SHALLOW CUT	EXPOSED	Gracilaria Bursa-Pastoris	6	10	4	
SHALLOW CUT	EXPOSED	Gracilaria Tikvahiae	6	0	x	
SHALLOW CUT	EXPOSED	Acanthophora	15	0	x	
SHALLOW CUT	ENCLOSED	Gracilaria Bursa-Pastoris	9	20	11	
SHALLOW CUT	ENCLOSED	Gracilaria Tikvahiae	20	32	12	
SHALLOW CUT	ENCLOSED	Acanthophora	13	10	-3	
SHALLOW CUT	ENCLOSED	Gracilaria Bursa-Pastoris	5	10	5	
SHALLOW CUT	ENCLOSED	Gracilaria Tikvahiae	4	10	6	
SHALLOW CUT	ENCLOSED	Acanthophora	6	22	16	
SHALLOW CUT	ENCLOSED	Gracilaria Bursa-Pastoris	2	11	9	
SHALLOW CUT	ENCLOSED	Gracilaria Tikvahiae	2	10	8	
SHALLOW CUT	ENCLOSED	Acanthophora	15	41	26	

Table 1B - Daily Site Conditions

DAILY SITE LOG											
DATE	WATER TEMP (°C)	DO (mg/L)	DO (%)	SAL (PSU)	pH	NTU	Chl (µg/L)	cDOM	DEPTH (m)	WEATHER	ADDITIONAL INFORMATION
WEDNESDAY	30.056	7.77		23.59	8.18	1.73	8.61	84.92	0.206		
7/11/2018	32.58	6.44		23.42	8.14	1.96	6.34	90.27	1.1	OVERCAST,	
	31.205	6.9	X	22.83	8.19	1.51	6.89	100.71	0.53	RAINY	
THURSDAY	30.26			23.64	8.04	2.54	10.32	97.4			
7/12/2018	30.4			23.44	7.88	1.22	4.52	98.51			
	30.86	X	X	23.04	8.12	1.14	4.67	100.9	X	OVERCAST	
FRIDAY	31.23	6.42	98.6	23.42	8.16	2.34	10.2	87.45		SUNNY,	
7/13/2018	30.924	5.43	83.1	24.21	8.04	2.02	6.12	93.59		WITH	
	30.821	4.75	72.8	24.22	8	0.84	4.57	96.58	X	SCATTERED	
MONDAY	32.576	6.72	X	24.06	8.08	2.85	18.75	86.6	0.152		BACK OF TARPON BAY: (1) 13 cm, (2) MISSING, (3) MISSING, (4) 13 cm, (5) 8 cm, (6) MISSING, (7) 13 cm, (8) 26 cm,
7/16/2018	30.805	X	X	23.77	7.9	2.24	7.99	99.5	X		GREEN POINT: (1) MISSING, (2) MISSING, (3) MISSING, (4) 15 cm, (5) MISSING, (6) MISSING, (7) 23 cm, (8) 12 cm, (9) 15 cm
	32.628	9.31	X	23.3	8.29	2.56	8.7	98.14	0.191	SUNNY, HOT	15 cm, (3) 11 cm, (4) 8 cm, (5) MISSING, (6) 20 cm, (7) 17 cm,
TUESDAY	32.611	5.61	88.5	24.27	7.93	2.14	5.72	95.06			
7/17/2018	32.706	9.18	144.5	23.82	8.21	1.29	6.81	99.27			
	31.82	5.75	89.2	23.85	7.93	1.97	6.3	100.84	X	SUNNY, HOT	CHECK AT 12 PM
WEDNESDAY	34.783	14.61	231.4	24.57		0.74					
7/18/2018	32.565	8.09	127.8	24.62		3.58					USED THE SMALLER YSI, SOME
	33.179	10.28	163	23.86	X	10.02	X	X	X	SUNNY, HOT	OF THE DATA MAY BE OFF
THURSDAY	33.253	9.66	105.4	24.72		5.77				SUNNY,	
7/19/2018	32.101	6.78	154.2	24.78		3.55				HOT,	USED THE SMALLER YSI, SOME
	32.516	8.58	135.4	24.41	X	3.29	X	X	X	OVERCAST	OF THE DATA MAY BE OFF
FRIDAY	32.914	8.51	135.2	24.74		1.02					
7/20/2018	32.899	7.71	122.5	25.09		2.93					
	33.032	6.02	95.6	24.74	X	8.14	X	X	X	SUNNY, HOT	CHECKED AT 2 PM
MONDAY	31.186	6.08	94.2	25.78		1.05					REMOVAL OF BAGGED
7/23/2018	30.265	4.7	72.3	26.05		1.82				OVERCAST,	MACROALGAE TO MEASURE
	30.899	5.56	86.5	26.19	X	2.49	X	X	X	RAINY	VOLUME DISPLACEMENT,
TUESDAY	32.136	9.86	156.4	26.09		1.15				SUNNY,	
7/24/2018	30.663	6.38	98.3	25.95		2.66				HOT, PARTLY	
	31.043	6.6	102.7	26.52	X	2.37	X	X	X	CLOUDY IN	CHECKED AT 2 PM
WEDNESDAY	32.122	9.02	144.5	26.35		1.6					CHECKED BETWEEN 1:30 AND
7/25/2018	21.184	6.6	103.1	26.29		3.78					3 PM, REMOVAL OF PLASTER
	31.226	6.82	106.5	26.58	X	2.78	X	X	X	SUNNY, HOT	OF PARIS CLODS
THURSDAY	32.512	9.54	154.6	26.9		1.37					CHECKED AT 3 PM, MADE NEW
7/26/2018	32.228	7.52	119	26.81		2.2					PLASTER OF PARIS CLODS TO
	32	6.92	109.3	26.95	X	2.52	X	X	X	SUNNY, HOT	BE DRIED AND PLACED ON
FRIDAY	32.363	8	127.7	27.31		2.53					
7/27/2018	31.728	6.04	95.1	26.58		1.98					
	31.704	7.71	120.5	26.31	X	1.51	X	X	X	'ARTLY CLOUD	CHECK AT 11:30 AM
MONDAY	30.578	7.97	122.7	25.66		3.12					CHECKED FROM 2:40-3:30 PM.
7/30/2018	30.735	6.14	94.4	25.05		2.2				CLOUDY,	PLACEMENT OF SECOND CLOD
	30.563	7.82	119.5	24.8	X	1.7	X	X	X	RAINING	TEST. (CLODS AT GP START
TUESDAY	29.636	6.14	93.4	25.4		3.04					
7/31/2018	29.874	5.8	88.4	25.75		2.75				SUNNY,	CHECKED BETWEEN 10:30-
	29.97	8.53	129.3	25.26	X	5.07	X	X	X	CLOUDY	11:00 AM
WEDNESDAY	30.979	10.82	164.5	25.71		2.5					CHECKED BETWEEN 3:45-4:30
8/1/2018	31.737	9.4	147.3	26.2		3.3					PM. REMOVAL OF CLOD
	32	6.92	109.3	26.95	X	2.52	X	X	X	OVERCAST	CARDS.
THURSDAY	29.515	4.61	68.7	25.81		4.16					
8/2/2018	30.843	4.96	76.1	26.72		3.38					
	29.918	8.34	126.4	25.77	X	1.62	X	X	X	SUNNY	HECKED BETWEEN 10:30-11:30 A
FRIDAY											
											DID NOT CHECK DUE TO
8/3/2018	X	X	X	X	X	X	X	X	X	.OUDY, RAININ	WEATHER CONDITIONS
MONDAY	30.069	0.93	14.8	26.46		2.11					CHECKED 9 AM. PUT OUT
	30.48	5.35	82.1	25.88		2.29					THIRD CLOD CARD TEST. DID
8/6/2018	30.205	5.51	84	24.92	X	1.02	X	X	X	SUNNY	NOT REPLACE MACROALGAE
TUESDAY	31.156	4.82	75.6	26.44		1.13					
	30.925	5.24	81.1	26.09		1.31					
8/7/2018	29.916	5.41	81.3	23.8	X	1.05	X	X	X	SUNNY	CHECKED 10:00-11:30 AM
WEDNESDAY	29.46	6.42	97.4	25.27		2.67					CHECKED 7:20-8:00 AM.
	30.397	5.17	79.2	25.21		1.79					REMOVAL OF ALL ALGAE AND
8/8/2018	29.808	4.78	72.1	24.11	X	1.42	X	X	X	SUNNY	CLODS.

Table 1C - Clod Card Data

PLASTER OF PARIS CLOD EXPERIMENT					
DATE	SITE	*Wi (g)*	*Wf (g)*	AREA (cm)	RATE OF DISSOLUTION
	CONTROL (BAY WATER IN LAB)	38.12	31.48	4.60714495	3.32
		29.91	7.63	0.439627107	11.14
		29.88	16.12	1.966242601	6.88
		29.87	14.22	1.531076746	7.825
		29.9	6.62	0.331163005	11.64
	BACK OF BAY	29.88	12.06	1.100529383	8.91
		29.9	11.2	0.947898599	9.35
		29	6.43	0.332119337	11.285
		29.86	10.36	0.813220123	9.75
		29.89	12.02	1.092509741	8.935
	GREEN POINT	29.89	1.97	0.029345995	13.96
		29.88	11.33	0.971330098	9.275
		29.9	9.23	0.643767782	10.335
		29.83	2.73	0.056583134	13.55
EXPERIMENT 1: 7/23-7/25		29.87	3.74	0.105910976	13.065
	SHALLOW CUT	29.89	1.82	0.025047199	14.035
	CONTROL (BAY WATER IN LAB)	26.17	20.17	4.013031456	3
		26.16	12.98	1.66319097	6.59
		26.17	16.88	2.810642779	4.645
		26.12	15.47	2.369749798	5.325
		26.17	13.07	1.685046704	6.55
	BACK OF BAY	26.16	12.18	1.464493033	6.99
		26.15	13.65	1.840730164	6.25
		26.13	18.02	3.212913006	4.055
		26.18	1.58	0.024606118	12.3
		26.18	11.85	1.384094137	7.165
	GREEN POINT	26.16	5.49	0.297534563	10.335
		26.16	9.63	0.91547251	8.265
		26.18	8.54	0.718860581	8.82
		26.15	1.51	0.022525722	12.32
EXPERIMENT 2: 7/31-8/1/2018		26.14	7.46	0.550217883	9.34
	SHALLOW CUT	26.17	1.61	0.025568928	12.28
	CONTROL (BAY WATER IN LAB)	25.32	20.68	4.506525978	2.32
		25.38	1.53	0.024550924	11.925
		25.27	12.15	1.561745578	6.56
		25.35	1.8	0.034060992	11.775
		25.37	1.5	0.023616188	11.935
	BACK OF BAY	25.35	10.58	1.176748412	7.385
		25.38	14.97	2.35032856	5.205
		25.32	17.49	3.223446222	3.915
		25.34	13.85	2.018155094	5.745
		25.36	14.5	2.208542286	5.43
	GREEN POINT	25.33	11.58	1.411935806	6.875
		25.36	7.04	0.520613029	9.16
		25.32	10.09	1.072810814	7.615
		25.35	1.59	0.026577035	11.88
EXPERIMENT 3: 8/7/2018		25.32	1.57	0.025974076	11.875
	SHALLOW CUT	25.31	0	0	12.655

Table 2 - Stipe Strength Test Data

Stipe Strength Test 1				
Species	Trial	Stipe (cm)	Branch (cm)	Force (g)
GBP	GBP,1	5	3	30
GBP	GBP,2	9.4	5.3	7
GBP	GBP,3	9.4	5.7	67
GBP	GBP,4	7.1	7	95
GBP	GBP,5	8.2	3.2	14
GBP	GBP,6	10.3	4	120
GT	GT,1	11.3	24	24
GT	GT,2	11.9	9.3	170
GT	GT,3	12.3	6.9	90
GT	GT,4	6.5	3.8	87
GT	GT,5	7.3	2.4	45
GT	GT,6	8.7	6.5	32
A	A,1	7	3.8	20
A	A,2	6.4	3.4	15
A	A,3	10.3	4.6	19
A	A,4	9.2	4	11
A	A,5	9.2	4.3	2
A	A,6	9.2	7	13

Stipe Strength Test 2				
Species	Trial	Stipe (cm)	Branch (cm)	Force (g)
GBP	GBP,1	11.5	4.7	120
GBP	GBP,2	10.8	3.3	180
GBP	GBP,3	10.8	3.6	190
GBP	GBP,4	8.7	16	180
GBP	GBP,5	9	3.1	120
GBP	GBP,6	9	3.2	100
GT	GT,1	9.4	4.2	120
GT	GT,2	6.4	7	50
GT	GT,3	6.8	90	4.2
GT	GT,4	6	0.6	60
GT	GT,5	4.1	3.9	60
GT	GT,6	6.8	7.2	120
A	A,1	10.4	5.2	20
A	A,2	9	5	30
A	A,3	4.5	2.4	30
A	A,4	4.5	3.4	40
A	A,5	4.5	4.4	30
A	A,6	7	1.3	30

Stipe Strength Test 3				
Species	Trial	Stipe (cm)	Branch (cm)	Force (g)
GBP	GBP,1	4.7	3.5	70
GBP	GBP,2	3.9	5.2	110
GBP	GBP,3	4.7	5.4	80
GBP	GBP,4	3.9	7.8	140
GBP	GBP,5	39	2.6	140
GBP	GBP,6	4.5	2.3	90
GT	GT,1	8.4	3	40
GT	GT,2	8.4	3.5	20
GT	GT,3	7.8	3.6	10
GT	GT,4	6.3	3.1	80
GT	GT,5	2.5	2.2	40
GT	GT,6	6.4	1.7	20
A	A,1	10.1	3.1	20
A	A,2	9.2	3.1	1
A	A,3	11.2	2.3	1
A	A,4	11.2	2	1
A	A,5	11.2	3.5	2
A	A,6	12.5	5.4	20

Average			
Species	Stipe (cm)	Branch (cm)	Force (g)
GBP,1	8.23	4.98	55.5
GT,1	9.67	8.82	74.67
A,1	8.55	4.52	13.3
GBP,2	9.97	3.25	148.3
GT,2	6.58	4.52	83.3
A,2	6.65	3.62	30
GBP,3	4.27	4.47	105
GT,3	6.63	2.85	35
A,3	10.9	3.23	7.5

Average	
Force (g)	Species
102.93	GBP
64.32	GT
16.93	A